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(54) Abstract Title
Radio communication systems

(57) A Time Division Duplex (TDD) radio communication system utilises adaptive rate matching determined in dependence upon propagation delay as determined at a base station and indicated to a mobile terminal with which it is in communication thereby to optimise efficiency of transmission operation so that channel operating time is not wasted. In one scheme described the bit rate is held fixed, a variable number of bits is declared lost in accordance with the propagation delay and error correction provided by trellis coding is relied upon to reinstate those bits.

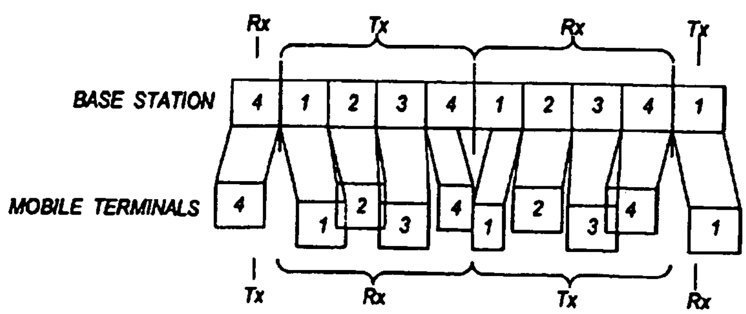

Fig.7

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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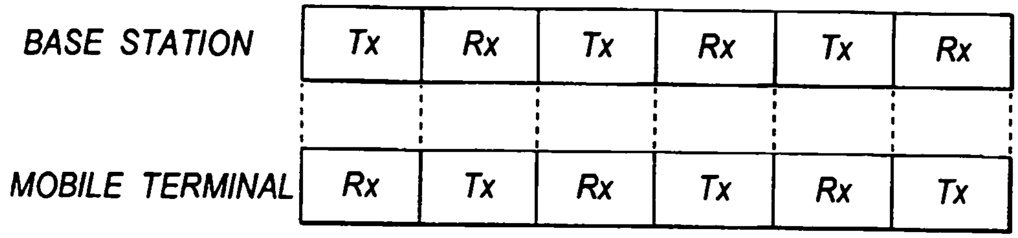

Fig.1

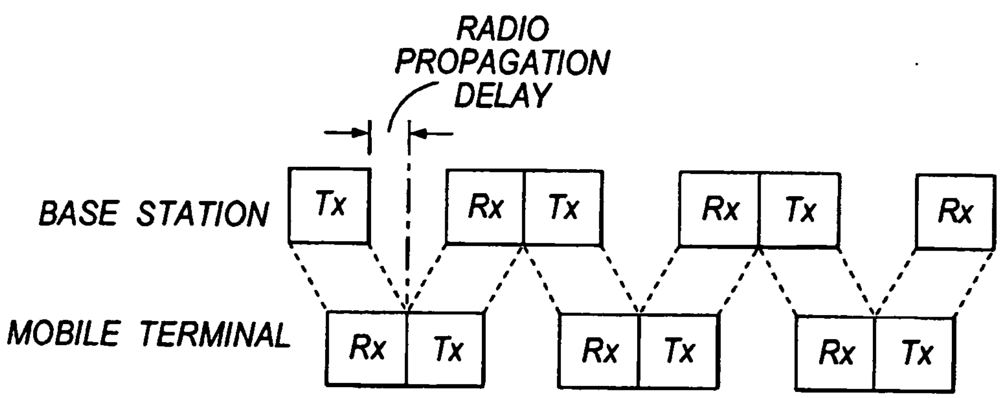

Fig.2

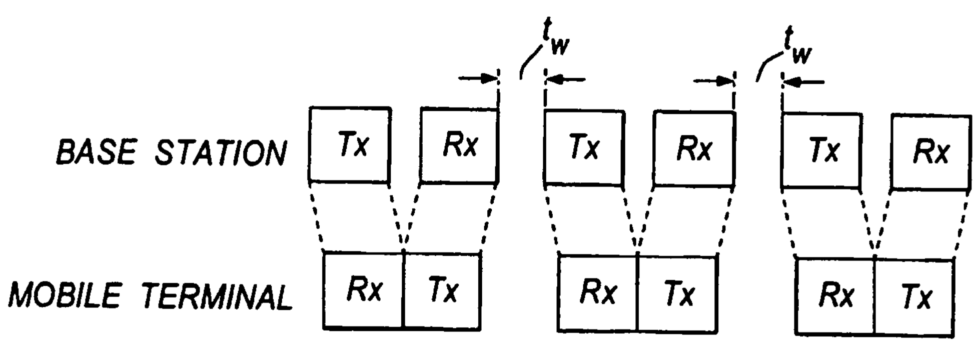

Fig.3

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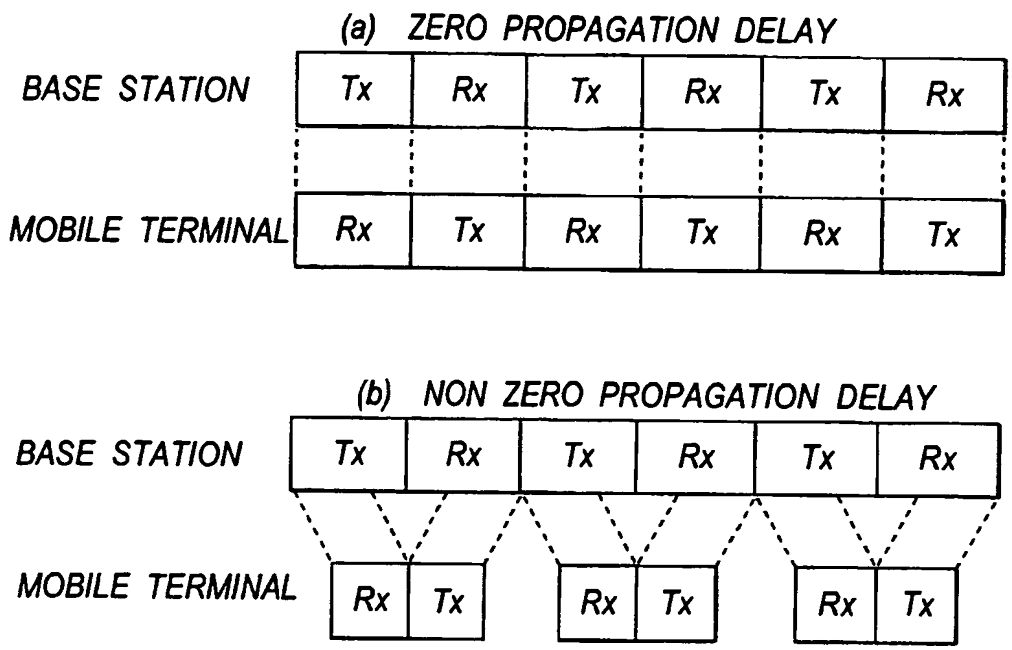
(a) ZERO PROPAGATION DELAY
BASE STATION
Tx
Rx
Tx
Rx
Tx
Rx
MOBILE TERMINAL
Rx
Tx
Rx
Tx
Rx
Tx
(b) NON ZERO PROPAGATION DELAY
BASE STATION
Tx
Rx
Tx
Rx
Tx
Rx
MOBILE TERMINAL
Rx
Tx
Rx
Tx
Rx
Tx

Fig.4

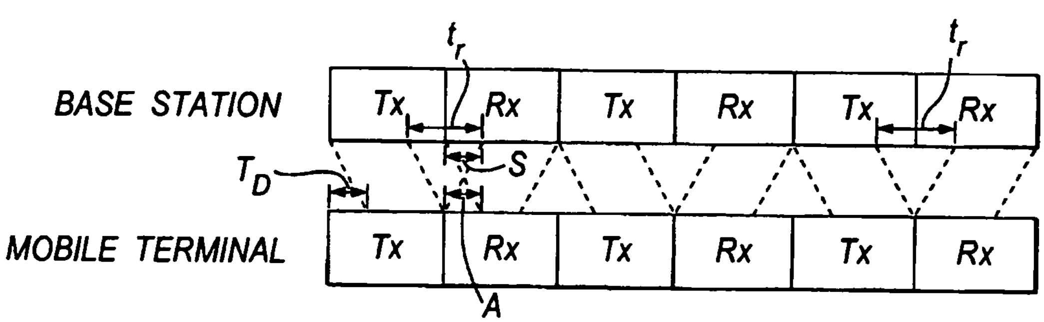
t_r
t_r
BASE STATION
Tx
Rx
Tx
Rx
Tx
Rx
T_D
S
MOBILE TERMINAL
Tx
Rx
Tx
Rx
Tx
Rx
A

Fig.5

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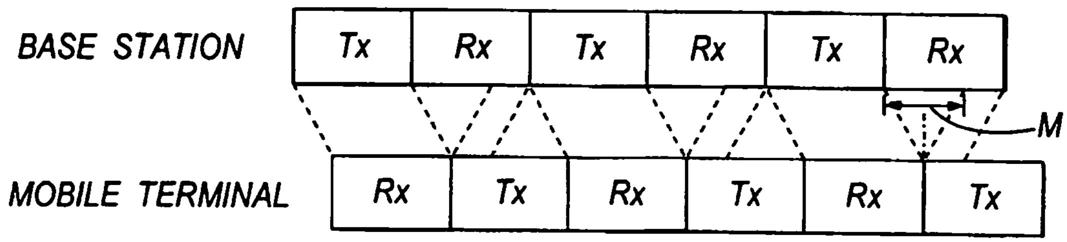

Fig.6

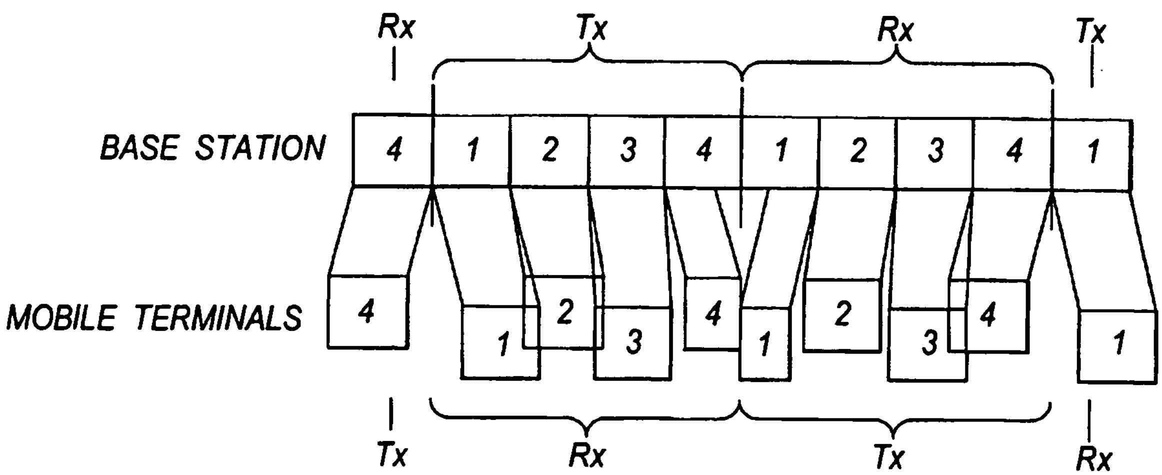

Fig.7

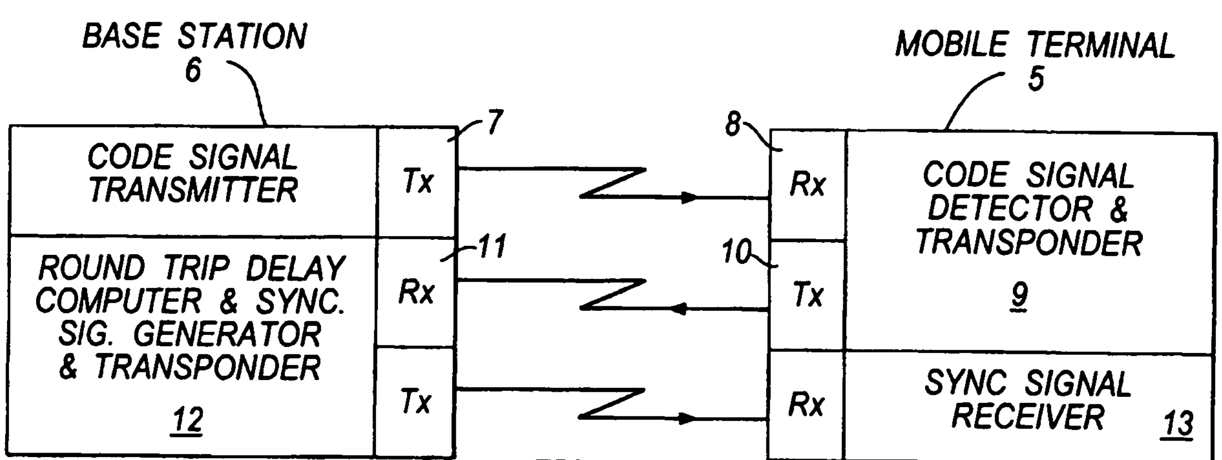

Fig.8

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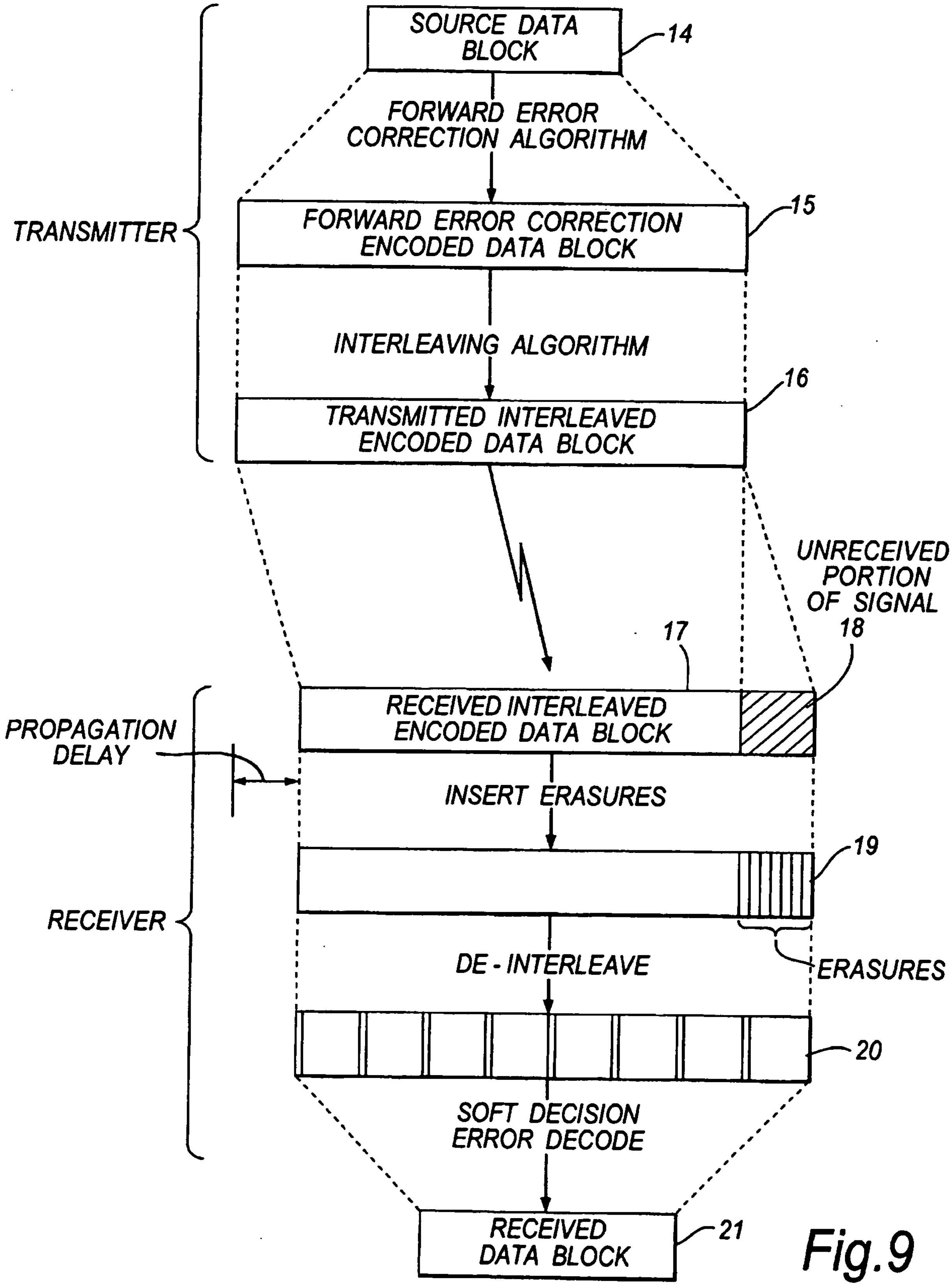
SOURCE DATA BLOCK
14
FORWARD ERROR CORRECTION ALGORITHM
FORWARD ERROR CORRECTION ENCODED DATA BLOCK
15
TRANSMITTER
INTERLEAVING ALGORITHM
16
TRANSMITTED INTERLEAVED ENCODED DATA BLOCK
UNRECEIVED PORTION OF SIGNAL
18
17
RECEIVED INTERLEAVED ENCODED DATA BLOCK
PROPAGATION DELAY
INSERT ERASURES
19
RECEIVER
ERASURES
DE - INTERLEAVE
20
SOFT DECISION ERROR DECODE
RECEIVED DATA BLOCK
21

Fig.9

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IMPROVEMENTS IN OR RELATING TO RADIO COMMUNICATION SYSTEMS

This invention relates to radio communication systems and more especially it relates to Time Division Duplex (TDD) communication systems.

TDD is a means for providing bi-directional radio communications using a single frequency. Very early TDD radio communications simply included a manually operated 'over key' used by an operator to switch between transmit and receive modes of operation. Present day TDD communication systems however, are much more sophisticated and might be used for the transmission of information between a base station and a mobile terminal for example, TDD being implemented by compressing signals for transmission by a factor of about 2 and formatting data into transmission time slots which are interleaved with reception time slots of a similar duration as shown in Figure 1 of the accompanying drawings. Although this TDD implementation would be appropriate for operation where radio propagation delay is negligible, in applications where propagation delay is appreciable, it becomes necessary to include a guard period having a duration corresponding to the maximum propagation delay and a TDD implementation which includes this is shown in Figure 2 of the accompanying drawings. It will be appreciated that with the implementation as shown in Figure 2, a significant proportion of the time is unavailable for transmission which results in a loss of capacity.

As shown in Figure 3 of the accompanying drawings, the base station transmit times are established according to a fixed clocking structure, and the mobile terminal derives its reception time from the signal received from the base station, and then transmits immediately after reception, and the base station receives the transmitted signal as it arrives, then for a fixed guard period, if the actual delay is smaller than that which can be accommodated, capacity is wasted corresponding to the time periods t_W as shown in Figure 3.

Other implementations are known in which information is obtained appertaining to propagation delay and the mobile terminal is arranged to delay its transmission to create symmetrical or near symmetrical transmit/receive patterns on both uplink and downlink. Which ever of these known implementations is used, known TDD systems lead to two problems, i.e. capacity is wasted for propagation delays (i.e. radio ranges) which are smaller than that accommodated by a design guard period, and for propagation delays/radio ranges greater than that accommodated by a design guard period, communication breaks down because data is lost.

It is an object of the present invention to provide a TDD communication system wherein the aforesaid problems are obviated at least in part.

Many modern digital radio communications systems make use of forward error correction coding (FEC) to provide coding gain and improved bandwidth efficiency (e.g. using Trellis Coded Modulation) and/or improved system capacity through improved

tolerance to interference e.g. in Code Division Multiple Access systems, (CDMA). In order to mitigate the effects of burst errors (due, e.g., to multipath fading) interleaving of the coded bits is frequently employed. Typically the types of codes used (convolutional or turbo codes) provide coded bit rates which are related to the source data rate by a ratio of two small numbers (e.g. 2, 3, 1.5). Often however, the source data rate cannot be related exactly to the over-the-air transmission rate by such a number. It is possible to overcome this difficulty by either deleting some of the transmitted coded bits or repeating some of the coded bits and this process is known as 'rate matching'.

According to the present invention as broadly conceived, a Time Division Duplex (TDD) radio communication system utilises adaptive rate matching determined in dependence upon propagation delay.

The radio communication system may comprise a base station adapted for TDD communication with at least one mobile terminal, the base station and each of the said terminal(s) having apparatus including an RF transmitter and an RF receiver, the base station apparatus additionally including computer means arranged to register the round trip RF signal propagation delay between a base station transmission and the reception at the base station of a reply from the mobile terminal, timer means for producing in dependence upon the round trip delay, control data which is multiplexed at intervals with source data from a base station interface, which source data is forward error correction encoded, interleaved and the multiplex thereby produced being

transmitted to the mobile terminal in consecutive base station transmission time slots and the mobile terminal including computer means arranged to adapt transmission time by a period determined in dependence upon the control data as received from the base station so that the timing of transmissions from the mobile terminal is synchronised with operation of the base station and adaptively adjusted in accordance with the range of the mobile terminal from the base station and wherein those parts of the transmission time slots from the base station to the mobile terminal and those parts of the transmission time slots from the mobile terminal to the base station which cannot be received at the mobile terminal and the base station respectively because of propagation delay effects are declared as erasures in the receiver prior to de-interleaving and soft decision error correction decoding so that the decision variables corresponding to these unreceiveable portions are set numerically to zero.

By adaptively adjusting the timing of mobile terminal transmissions in dependence upon RF signal propagation delay/range and by declaring erasures for parts of the transmissions which cannot be received, efficiency of operation is optimised so that channel operating time is not wasted.

Although the control data may be comprehensively transmitted in each base station transmit time slot, it is envisaged that alternatively it may be distributed over several such time slots in order to minimise the bandwidth used. This is possible because the propagation delay changes relatively slowly.

The radio communication system may comprise a plurality of mobile terminals arranged in Time Division Duplex (TDD)/Time Division Multiple Access (TDMA) communication with a base station wherein the time of transmission from the mobile terminals is adaptively adjusted in accordance with the range of the mobile terminal concerned from the base station and wherein that mobile terminal which transmits last in a TDMA sequence operates to inhibit reception of signals from the base station at a time from the start of reception corresponding to a reception slot period duration minus half the round trip delay as indicated by the code as determined at the base station in dependence upon RF signal propagation delay.

Some embodiments of the invention will now be described by way of example only with reference to Figures 4 to 8 of the accompanying drawings in which;

FIGURE 1 herein before referred to, is a diagram showing the relationship between transmission and reception time slots in a known TDD communication system comprising a base station and a mobile terminal with no signal propagation delay there between;

FIGURE 2 herein before referred to, is a diagram similar to Figure 1 showing the relationship between transmission and reception time slots in a known TDD communication system comprising a base station and a mobile terminal but with appreciable propagation delay;

FIGURE 3 herein before referred to, is a diagram similar to Figure 2 showing the relationship between transmission and

reception time slots in a known TDD communication system comprising a base station and a mobile terminal with some propagation delay and including a guard period longer than the propagation delay;

FIGURE 4a is a diagram showing the relationship between transmission and reception time slots in an adaptive TDD communication system comprising a base station and a mobile terminal wherein propagation delay is zero;

FIGURE 4b is a diagram similar to Figure 4a showing the relationship between transmission and reception time slots in an adaptive TDD communication system comprising a base station and a mobile terminal but wherein the propagation delay is not zero;

FIGURE 5 is a diagram similar to Figure 4a showing the relationship between transmission and reception time slots in an adaptive TDD communication system comprising a base station and a mobile terminal but wherein operation is synchronised;

FIGURE 6 is a diagram similar to Figure 5, showing the relationship between transmission and reception time slots in an adaptive TDD communication system comprising a base station and a mobile terminal but wherein operation is unsynchronised;

FIGURE 7 is a diagram showing the relationship between transmission and reception time slots in an adaptive TDD/TDMA communication system comprising a base station and a mobile terminal;

FIGURE 8 is a flow diagram showing the sequence of operational steps carried out by apparatus comprising a base

station and a mobile terminal in an adaptive TDD communication system, and,

FIGURE 9 is a signal diagram showing the steps involved in forward error correction coding, interleaving, transmission, erasure declaration, de-interleaving, and error correction.

In this invention, 'variable rate matching' is used to provide an adaptive system which serves to accommodate the different radio ranges which obtain in a TDD based digital radio communications system without waste of transmission time and in one proposed scheme a receive/transmit structure in the base station of the system is held fixed regardless of the propagation delay and this scheme will now be described with reference to Figures 4a and 4b.

Referring firstly to Figure 4a, in a zero propagation delay case as shown, the structure is identical to that of Figure 1 and the transmission is effectively 100% efficient in terms of utilisation of the available time. However, in a non-zero propagation delay case as shown in Figure 4b, and as explained earlier herein, although the base station structure is unaltered, because of the propagation delay, the mobile terminal is unable to receive the last part of the base station's transmission. Moreover, the base station is unable to receive anything during the last part of the mobile terminal's transmission. However, if a suitable coding and interleaving strategy is employed using conventional techniques well known to those skilled in the art, the mobile terminal can declare the last part of the transmission from the base station as erasures prior to de-interleaving and error correction decoding and a similar

process can be employed for the base station receiver. Thus the only effect of an increasing radio propagation delay is a corresponding increase in the code rate. The advantages of this procedure are that there is no wasted capacity when the system using the TDD scheme is operated at short range and a very high upper limit can be set on the maximum range without compromising the short range performance.

In the system described above it will be appreciated that it is not essential to foreshorten the receive and transmit periods in the mobile terminal and alternatively, as illustrated in Figure 5, redundant reception and/or transmission periods t_r may simply be included, the duration of which is adapted in dependence upon propagation delay so that there is no waste of transmission time. There is no particular benefit in failing to foreshorten the receive and transmit periods except that the control functions are simplified

In order to implement adaptive operation as just before described various operations must be performed:-

a) The mobile terminal's TDD frame must be synchronised to the base station's TDD frame. Note that this is *not* simply achieved by synchronising the mobile terminal's receiver to the base station's transmitter

b) The mobile terminal must determine when the transmission of valid data from the base station begins and ends. Since it is known that no data is lost from the beginning of the transmission burst, the beginning of the

data can be recognised from synchronisation data contained within the burst(s). If the frames have been synchronised then the end of the burst can be recognised as being simply the last bit which can be received before it is necessary to switch to transmit.

c) The base station must determine when the transmission of valid data from mobile terminal begins and ends. Identical arguments to those in 'b' apply here.

Thus, it will be appreciated that a key requirement for operating adaptive TDD is synchronisation of the mobile terminal's TDD frame to the base station's TDD frame. Consider an adaptive TDD system in which this synchronisation has yet to be achieved. Suppose that the mobile terminal's TDD frame is established on the basis of zero propagation delay when in fact the propagation delay is non zero as illustrated in Figure 6.

Referring now to Figure 6, in this case the mobile terminal is receiving the whole of the base station's transmission but a doubled portion of the mobile terminal's transmission is lost at the base station. Suppose that a synchronisation burst is transmitted from both the base station and the mobile terminal at a position in the transmission slot far enough from its end so as not to be lost under any conditions of synchronisation. Suppose also, that the position of the synchronisation burst within the base station transmission is identical to that within the mobile terminal transmission (if this is not the case then suitable compensation must be applied). The delay between the base station sending its

synchronisation burst and receiving the corresponding synchronisation burst from the mobile terminal will, for the condition shown in Figure 6, be equal to one slot period plus a measure of the round trip propagation delay M. Let the base station take this measured round trip propagation delay M, code it digitally and transmit it at regular intervals to the mobile terminal as part of its transmission. As herein before emphasised it is essential that the position within the transmission of this code should be such that it can be correctly decoded when the frame of the mobile terminal is incorrectly synchronised to the frame of the base station.

Referring now to Figure 6, it can be seen that the switching from Rx to Tx is related directly to the reception of the signal from the base station. This relationship can be viewed as being a timing advance, A, of zero. In general, this timing advance will be greater than zero. In general, if A is non-zero, the measurement at the base station, S, will be smaller than the round trip delay by A.

Thus:

$S = T_D - A$

In order to achieve correct operation, we require that the advance A, is equal to the one way delay, $T_D/2$. Let the value of A, at the nth update be A_n. Then we obtain the n+1th update by:-

$A_{n+1} = (S + A_n) / 2$

It is clear that this will instantly correct the unsynchronised situation as shown in Figure 6 to that of Figure 5. In this case A_0 is zero and $S = T_D$ so A_1 is immediately set to $T_D/2$.

It is envisaged that the adaptive approach as described herein can be extended to a TDD/TDMA system in which one base station is in Time Division Duplex/Time Division Multiple Access communication with a plurality of mobile terminals. Consider the fixed TDD/TDMA structure as illustrated in Figure 7. This shows a regular structure for TDD/TDMA with matched uplink and downlink capacity supporting links to four terminals. The mobile terminals are at varying ranges from the base station. The diagram shows that only one downlink slot 4 and one uplink slot 1 per frame need reduced duration. In the same way as for the pure TDD case, the base station measures the round trip propagation delay, this time for each of the mobile terminals. In the downlink, all terminals synchronise to the downlink transmissions. In the uplink, the terminals advance their transmissions by the one way delay. Additionally, on the downlink, the last mobile terminal in sequence, stops reception at a time given by the start of reception, plus the slot duration, minus the one way delay. In this way the mobile will stop reception before any uplink transmissions can interfere with its reception. Moreover, at the start of the uplink frame, the terminal using the first slot will not transmit the waveform corresponding to the first one way propagation delay period of its slot. Note that there is no loss of capacity when switching from uplink to downlink transmission direction.

For the case of asymmetrical operation the operation is identical. The loss of capacity is always around the switch from

downlink to uplink direction, irrespective of whether the adjacent slots are for the same user or not.

For flexible TDD/TDMA there will be several switching points between downlink and uplink per frame. Each of these will have its associated loss in capacity.

In order to facilitate an understanding of the invention, the sequence of communication events which take place in order to achieve synchronisation adaptively of a mobile terminal 5 with a base station 6 will now be described with reference to Figure 8.

Initially, the base station 6 is arranged to transmit a predetermined code from a code signal transmitter 7, to a receiver 8, of a code signal detector and transponder 9 in the mobile terminal 5. A transmitter 10 of the code signal detector and transponder 9, transmits a return code in the following uplink slot which is received by a receiver 11 in a round trip delay computer/sync signal generator and transponder 12, which operates to transmit a sync signal to a sync signal receiver 13 in the mobile terminal, which is utilised thereby to achieve synchronisation adaptively in dependence upon RF propagation delay as indicated by the predetermined code as aforesaid which is continuously updated.

As already explained herein, it is essential that the synchronising operation is not corrupted by the effects of RF signal propagation delays and accordingly a period for transmission of signals required to achieve synchronisation is chosen during transmission time slots which is sufficiently far from the end of the time slot to be unaffected.

For further clarification of the operation of the rate matching function, Figure 9 is described in detail. It illustrates transmissions from the mobile terminal to the base station or from the base station to the mobile terminal. For clarity one direction, from the mobile terminal to the base station will be described. A source data block 14, comprises the data bits which must be communicated from the mobile terminal to the base station in one time slot. Forward error correction coding is then applied to this to generate a forward error correction encoded data block 15. This process may take one of a number of forms, such as convolutional coding, turbo coding, or Reed-Solomon coding. For the purposes of rate matching it is desirable, however, that the code chosen should be amenable to soft decision decoding as familiar to those skilled in the art. The data block 15 contains more bits than the data block 14 because of the addition of redundant data bits. An interleaving algorithm is applied to the data block 15 to separate adjacent bits in the codeword during transmission. This is desirable for the case where short term signal fading may occur during the transmission of the data. A regular interleaver has been assumed although other interleaving structures are not precluded. An interleaved encoded data block 16, so generated is then transmitted from the mobile terminal and received at the base station as the received interleaved encoded data block 17. This block will consist of a set of non binary decision variables, one per transmitted bit. The sign of these decision variables conveys the bits most likely value (either one or zero) and the absolute numeric value increases monontonically

with the reliability of the received bit as familiar to those skilled in the art. These decision variables are known as soft bits. The last part 18 of the transmission from the mobile terminal cannot be received at the base station because of propagation delay. However, the start of the period which cannot be received is known since this begins with the start of the transmission period at the base station. Those bits which cannot be received are declared as erasures 19, by setting their numerical value in the receiver to zero. The soft bits including the erasures are then de-interleaved 20. The erasures are now spread over the frame. Finally the appropriate soft decision error correction decoding algorithm for the forward error correction code is applied in order to obtain the estimate 21 of the transmitted data.

It will appreciated that in the foregoing description as described with reference to Figures 4, 5, 6 and 7, guard periods have been shown as reduced to zero. However, the guard period referred to as being reduced to zero, is that directly associated with the radio propagation delay. This disclosure is not intended to preclude the inclusion of a guard period for other purposes such as the time taken to switch between receive and transmit modes, etc.

Various modifications may be made to the apparatus as hereinbefore described without departing from the scope of the invention as will be apparent to those skilled in the mobile radio communication art.

CLAIMS

1. A Time Division Duplex (TDD) radio communication system which utilises adaptive rate matching determined in dependence upon propagation delay.

2. A Time Division Duplex (TDD) radio communication system as claimed in Claim 1, comprising a base station adapted for TDD communication with at least one mobile terminal, the base station and each of the said terminal(s) having apparatus including an RF transmitter and an RF receiver, the base station apparatus additionally including computer means arranged to register the round trip RF signal propagation delay between a base station transmission and the reception at the base station of a reply from the mobile terminal, timer means for producing in dependence upon the round trip delay, control data which is multiplexed at intervals with source data from a base station interface, which source data is forward error correction encoded, interleaved and the multiplex thereby produced being transmitted to the mobile terminal in consecutive base station transmission time slots and the mobile terminal including computer means arranged to adapt transmission time by a period determined in dependence upon the control data as received from the base station so that the timing of transmissions from the mobile terminal is synchronised with operation of the base station and adaptively adjusted in accordance with the range of the mobile terminal from the base station and wherein those parts of the transmission time slots

from the base station to the mobile terminal and those parts of the transmission time slots from the mobile terminal to the base station which cannot be received at the mobile terminal and the base station respectively because of propagation delay effects are declared as erasures in the receiver prior to de-interleaving and soft decision error correction decoding so that the decision variables corresponding to these unreceiveable portions are set numerically to zero.

3. A Time Division Duplex (TDD) radio communication system as claimed in Claim 2, wherein the control data is comprehensively transmitted in each base station transmit time slot.

4. A Time Division Duplex (TDD) radio communication system as claimed in Claim 2, wherein the control data is distributed over several time slots in order to minimise the bandwidth used.

5. A Time Division Duplex (TDD) radio communication system as claimed in any preceding Claim, comprising a plurality of mobile terminals arranged in Time Division Duplex (TDD)/Time Division Multiple Access (TDMA) communication with a base station wherein the time of transmission from the mobile terminals is adaptively adjusted in accordance with the range of the mobile terminal concerned from the base station and wherein that mobile terminal which transmits last in a TDMA sequence operates to inhibit reception of signals from the base station at a

time from the start of reception corresponding to a reception slot period duration minus half the round trip delay as indicated by the code as determined at the base station in dependence upon RF signal propagation delay.

6. An adaptive TDD radio communication system substantially as hereinbefore described with reference to Figures 4 to 6, 8 and 9 of the accompanying drawings.

7. An adaptive TDD/TDMA mobile radio communication system substantially as hereinbefore described with reference to Figure 7 of the accompanying drawings.

The Patent Office

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INVESTOR IN PEOPLE

Application No: GB 9818303.1
Claims searched: 1 to 7
Examiner: Ken Long
Date of search: 17 March 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H4M (MTQX1, MTQA1)
H4L (LDC)

Int Cl (Ed.6): H04J (3/06)
H04L (5/14)

Other: ONLINE : WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2318026 A	MOTOROLA	None
A	US 5745484	OMNIPOINT	None
A	US 5355368	ALCATEL	None

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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E Patent document published on or after, but with priority date earlier than, the filing date of this application.